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A CATALOG OF PROTON EVENTS 1966-1976 HAVING NON-CLASSICAL SOLAR--ETC(U)

MAY 78 J P CASTELLI, G L TARNSTROM

UNCLASSIFIED AFGL-TR-78-0121 NL

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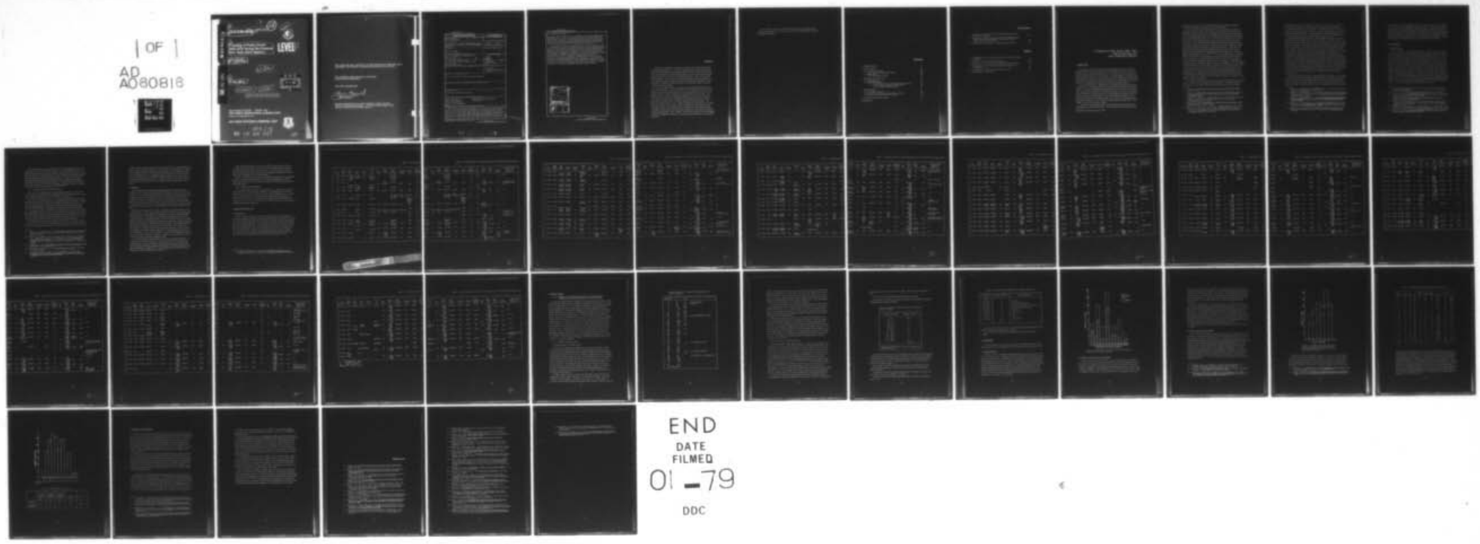

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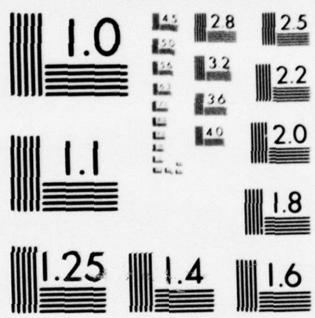

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A Catalog of Proton Events 1966-1976 Having Non-Classical Solar Radio Burst Spectra.

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JOHN P. CASTELLI
GUY L. TARNSTROM

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FOR THE COMMANDER

John Howard

Chief Scientist

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A catalog of about 118 proton events, 1966-1976, not included in an earlier catalog of 81 events (AFGL TR-77-0081) for the same period, is presented. These 118 events combined with the earlier 81 provide the basis for summarizing solar radio burst/high-energy proton correlation and prediction signature work. In the earlier effort, hereafter called Catalog I, the starting point was the identification of all solar radio bursts having the classical U-shape spectrum, and then establishing proton event association for the purpose of → next page

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devising a reliable "false-alarm" free predictor of the major proton events (equivalent PCA 2-2.5dB). In the present effort, the starting point is the identification of all other proton events not included in Catalog I ("misses" by the U-shape spectrum criteria), and then searching for and establishing solar radio correlations and possible predictions of weaker proton events. There are very few real misses of principal proton events.

Though the identification of proton events may be difficult at times, the solar correlation is still more difficult and often somewhat subjective; nevertheless, fairly reliable proton event/radio burst association has been generally found. The radio burst signature most often found for events in the present effort (Catalog II) is: the burst is of fairly long duration (≥ one hr), the emission is broadband (over 1000 MHz or more), the spectrum is reasonably flat between 1400 and 8800 MHz with peak flux densities about 100×10^{-22} w m^{-2} Hz^{-1}, and the burst integrated flux density is (at any centimeter wavelength) approximately 10^{-17} J m^{-2} Hz^{-1}. In contrast to classical U-shape spectrum events, where 2700 MHz usually has the lowest peak emission, here the 2700 MHz region might be the dominant one. Delay to first onset of protons is discussed. In contrast with delays for events in Catalog I, it is found to be generally longer for Catalog II events.

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Preface

This report represents a milestone of sorts in the solar radio burst/proton event prediction studies area. For more than fifteen years, the Solar Radio Section of the Transionospheric Propagation Branch of AFGL has directed its efforts toward the prediction of "catastrophic" geophysical events caused mainly by high energy protons which impact on AF and DOD operations. Some successes have been recognized. The effort has included many disciplines from component procurement through system design to equipment operation and maintenance. In the final analysis, however, quality data alone are the fuel which makes creditible scientific research possible.

Our deepest appreciation goes to those who made the collection and dissemination of data possible. First, we would like to acknowledge the dedication of the officers and men of the Air Weather Service who have performed so admirably as partners with us at Sagamore Hill and associated stations over the years. We would like to commend our colleague Mr. William Barron for the exemplary job he has done from the outset in verifying and archiving every piece of collected data, while at the same time carrying out independent research studies. Mr. Barron's uncanny ability to spot mistakes which humans and sometimes machines are prone to make, is a rare gift. In this category also are the often not-fully-appreciated present and former editors and co-editors of Solar Geophysical Data, J. Virginia Lincoln, Helen Coffey and Hope Leighton and of the AFCRL Geophysics and Space Data Bulletin, Anne L. Hilton. Special lists of proton events painstakingly compiled by Peggy Shea and Don Smart and graciously shared with us, have helped immensely.

We would like especially to thank Dr. Jules Aarons for his appreciation of merit and scope of the solar radio effort, and for his encouragement in carrying out these investigations.

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A Catalog of Proton Events 1966 - 1976 Having Non-Classical Solar Radio Burst Spectra

1. INTRODUCTION

Among the various solar and solar-geophysical phenomena which take place, perhaps the only class which might be termed catastrophic — at least in terms of possible effects on man and his operations — are the solar flare-associated proton events (energies $\gtrsim$10 MeV). It is, therefore, not surprising that a need has arisen to predict these events. The need has become greater as electronic communication, surveillance, and navigation systems have become more sophisticated, to say nothing of man's penetration into space with manned and unmanned vehicles.

In the past fifteen years, different research studies have addressed short and long range solar activity and geophysical event predictions with various degrees of success. Overall, moderately long range predictions, (a few hours to a few days) which depend on the development of morphological features of solar active regions, have not advanced as rapidly as hoped for considering the large amount of observational and research effort expanded. Short range predictions, however, have advanced nicely thanks to the combined efforts of numerous observational groups and sundry disciplines, but with radio patrol data playing a dominant role. In this activity, the Air Force has been a leader.

From the time when people started to take prediction work seriously, radio observations have been in the forefront. At first there was a tacit agreement that

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the type IV solar radio burst provided the best single correlation with proton activity and, therefore, showed most promise as a predictor.

In the mid 1960's when the USAF became seriously involved in geophysical predictions, it became rather clear that there were diverse impressions of just what constituted a type IV event. Assuming that a type IV burst was a dekameter to meter wavelength phenomenon, it was apparent that the type IV burst alone was not well correlated with proton activity, or at least not with the polar cap absorption effect from the >10 MeV protons. There were many more type IV's than proton events. Correlation improved when centimeter wavelength burst activity was added to the type IV events as a necessary requirement. (Perhaps this addition specifies what truly constitutes a type IV burst.) Even so, radio emission characteristics not narrowly defined would still produce many "false alarms." When it was specified that the centimeter-burst at any frequency had to exceed 1000 solar flux units (1Sfu = 1×10^{-22} W m^{-2} Hz^{-1}), the false alarm rate dropped rapidly. The ultimate in "false alarm"-free solar radio burst/PCA correlation was reached when one considered the burst peak flux density across the entire meter to centimeter wavelength range and observed a spectrum resembling a "U" with flux densities $\geq$1000 Sfu at high cm and low m wavelengths.[1, 2, 3] Subsequently, O'Brien[4] modified the criteria slightly to exclude the less important events. The burst spectrum, therefore, was the prediction tool to be used. Early, it was recognized how well the scheme worked by testing it against Bailey's list[5] of 48 principal PCA's for sunspot cycle 19. There for the 48 events listed – some of which apparently emanated from the far side of the sun and some of which were associated with flare/ bursts with mediocre quality radio data – a success rate of about 75 percent was realized.[1]

For sunspot cycle 20, the success rate in predicting principal PCA's was even greater using the meter-centimeter U-shape signature. It has been pointed out elsewhere[6] that of 81 radio events observed between 1966 and 1976 having the

1. Castelli, J.P. (1968) Observation and Forecasting of Solar Proton Events, AFCRL-68-0104.
2. Castelli, J.P. (1969) Short term prediction of solar proton events, Proc. of Sump. on Ionospheric Forecasting, Grey Rocks, Canada, Conference Proceedings No. 49.
3. Castelli, J.P., Aarons, J., and Michael, G.A. (1967) Flux density measurements of radio bursts of proton producing and non-proton flares, J. Geophys. Res. **72**:5491-5498.
4. O'Brien, W.E. (1970) The Prediction of Solar Proton Events Based on Solar Radio Emissions, AFCRL-70-0425.
5. Bailey, D.K. (1964) Polar cap absorption, Planetary Space Sci. **12**:495-541.
6. Castelli, J.P., and Barron, W.R. (1977) A catalog of solar radio bursts of 1966-1976 having spectral characteristics predictive of proton activity, J. Geophys. Res. **82**(No. 7):1275-1278.

U-shape spectrum, at least 80 had proton association. (The present paper modifies that figure slightly.) In other words, the "false alarm" rate using the "U-shape" spectrum criteria is very small. To achieve this success, it was necessary to provide for improved calibration accuracy of the absolute solar flux and day-to-day consistency of data. As an additional aid toward PCA prediction accuracy, an entirely new burst classification also had to be devised.[7, 8, 9, 10, 11]

Regarding principal PCA's ($\gtrsim$ 2 - 2.5 dB at 30 MHz) 1966-1976, there were perhaps a few events which would have been missed by the U-shape criteria. The present report will identify them. It never was expected that a single set of criteria could be developed for the prediction of all proton or PCA events from the largest down to the smallest. Since only the larger events impact significantly on operational systems, there was no real need to worry about the small events. Nevertheless we have considered almost all proton and PCA events within reason. Those not included in Catalog I of 81 events are included here. The present report/catalog does not label all proton/PCA events 1966-1976 not included in catalog I as "misses." Even though the proton event may be relatively small in intensity, the objective is to determine not merely radio association, but also the characteristics of the radio emission of the events identified as proton events in order to determine if these events, as a group, have some salient feature or other radio-identifying characteristic which might make their prediction possible from solar radio patrols. It is also desirable to investigate whether the delay to first onset of protons or to the start of the PCA from the flare-burst, is different for the two groups. It seems that it is.

There are numerous problems in developing statistical results. In some ways data have improved with technology progress, but this very progress has created a new set of conditions which militates against the use of a long time data base. Specific problems were determining start, max, and end time of proton events for different energies or coping with dissimilarity of timing information for the same

7. Castelli, J.P., and Aarons, J. (1968) The spectra of microwave solar bursts, Astron. J. Supplement **72**(Pt II)(5):S57-S58.

8. Castelli, J.P., and Guidice, D.A. (1970) On the distribution and interpretation of microwave solar burst data, Proc. 1970 G-AP International Symposium, Columbus, Ohio, p. 83-93.

9. Castelli, J.P., and Guidice, D.A. (1972) On The Classification, Distribution and Interpretation of Solar Microwave Burst Spectra and Related Topics, AFCRL-72-0049.

10. Guidice, D.A., and Castelli, J.P. (1972) Spectral characteristics of microwave bursts, Proc. of NASA Symp. on High Energy Phenomena on the Sun, Greenbelt, Md, NASA SP-342, pp. 87-103.

11. Guidice, D.A., and Castelli, J.P. (1975) Statistical characteristics of the peak flux density spectra of solar microwave bursts, Solar Physics **44**: 155-172.

energy band, derived from different vehicles. Sensitivity differences of different sensors (early vs recent vehicles) impacted severely on "start," that is, delay information. PCA timing/intensity information greatly different from station-to-station and hemisphere-to-hemisphere, implied the need for the almost impossible task of normalization. Other problems will be noted in discussing data sources. Ultimately precise statistical results for many events was impossible to arrange, and trend information better describes some of the results of the effort.

2. DATA SOURCES

2.1 Protons, PCA Events

The starting point in researching data for this catalog of anomalies by the U-shape criteria, was the collection of all PCA and proton information. Since the USAF through AWS for the period in question has operated a program – "SESS" (Space Environmental Support System) dedicated to the collection and use of all solar and particle data which might impact on operations – vast amounts of these data from world-wide military, civilian and educational research groups have been conveyed to AWS and disseminated in pseudo-real time by the Air Weather Service. The first source of data, therefore, were archived data from the TTY message terminal at Sagamore Hill. PCA data reported there were collected at Thule, Shepherd's Bay, McMurdo in the Antartic, and at other sites. Sometimes intensity, timing and other parameters reported promptly were later revised. Hence, later reviews and publications such as the NOAA Solar Geophysical Data,[12] Reports by Cormier[13, 14] listing PCA data from the Air Force Thule Station, and numerous reports and journal articles by Masley[15, 16, 17, 18] and others listing data from the McDonell-Douglas riometer stations were used.

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12. National Oceanic and Atmospheric Administration (1966-1976) Solar Geophysical Data Bulletins.
13. Cormier, R.J. (1970) Polar Riometer Observations, AFCRL-70-0690.
14. Cormier, R.J. (1973) Thule Riometer Observations of Polar Cap Absorption Events (1962-1972), AFCRL-TR-73-0060.
15. Masley, A.J. (1971) The McDonnell Douglas Geophysical Observatory Progress Report X, MDC-G2736.
16. Masley, A.J., and Satterblom, P.R. (1969) A discussion of solar cosmic ray activity near sunspot maximum, Proc. 11th Int. Conf. on Cosmic Rays, Budapest, 1969, p. 513-519.
17. Masley, A.J., McDonough, J.W., and Satterblom, P.R. (1970) Solar Cosmic Ray Observations During 1969, Antarctic Journal of the U.S., 5(No. 5):127.
18. Masley, A.J. (1974) The McDonnell Douglas Geophysical Observatory Program Progress Report XII, MDC G5190.

Proton data used were those reported by the various satellite systems; OGO, Explorer/Imp, Vela, ATS-1, GEOS, Pioneer, etc. Regonizing that it is best if a single source (vehicle) of proton data could be used, we have relied heavily on data from the "Explorer" vehicles whenever possible. These have been mainly found in the NOAA Solar Geophysical Data monthly reports.[12] At times proton data or information derived by private communication – with researchers having basic responsibility for particle measuring systems carried aboard different satellites and having custody of the raw data accumulated – were used. Reports and publications which contained valuable lists were[19, 20, 21, 22, 23].

2.1.1 PCA AND PROTON EVENT CRITERIA

The criteria for including a PCA event was generally the fact of the report from the various riometer data collecting agencies that a PCA had occurred. The PCA at 30 MHz might be as small as a few tenths of a decibel.

The criteria for listing an event as a proton event was an increase in proton flux above the background in channels, including predominantly 10 MeV or >10 MeV proton energy. For most vehicles, an increase of 0.2 protons cm^{-2} sec^{-1} str^{-1} could be reliably detected. Proton flux increases in lower (or higher) energy channels sometimes helped in resolving small increases in >10 MeV channels.

Once a proton event was identified, a more difficult task was to derive reliable data regarding the start time, max time, max intensity, and duration of the event. It is most difficult to derive consistent statistical data from different events, where sometimes different vehicles observed the different events and where the sensors of the two vehicles were different in sensitivity or even channel width.

A quantitative normalization of data was not attempted. Some weak events at first "suspect," were more or less validated when more than one vehicle observed the event. The larger the event became, the less suspect it was. However, events

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19. Castelli, J.P., and Aarons, J. (1970) Short Term Prediction of Solar Proton Events, McGraw Hill Yearbook of Science and Technology, D.N. Lapedes, Ed., pp. 353-357.

20. Dodson, H.W., Hedeman, E.R., Kreplin, R.W., Martres, M.J., Obdriko, V.N., Shea, M.A., Smart, D.F. and Tanaka, H. (1975) Catalog of Solar Particle Events 1955-1969, Vol. 49 of Astrophysics and Space Science Library, Ed. by Z. Svestka and P. Simon, D. Reidel Pub. Co., Dordrecht, Holland.

21. Carrigan, A.L., Ed. (1970) AFCRL Geophysics and Space Data Bulletin, 1970 (4th Quarter-1974, Appendix A).

22. Shea, M.A., and Smart, D.F. (1978) Significant Proton Events, 1955-1969, AFGL-TR-78-0028.

23. Van Hollebeke, M.A.I., Sung, L.S., and McDonald, F.B. (1975) The Variation of Solar Proton Energy Spectra and Size Distribution with Heliolongitude, Solar Physics, 41, pp. 189-223.

whether large or small which may have been associated with far-side flare-bursts, are almost impossible to predict and be correlated with an identifiable solar flare/burst. Weak to moderate "events" associated with co-rotating regions also occur and are difficult to predict. This general area is beyond the scope of this study. From the foregoing, it is to be expected that the present list will contain proton events not correlated with radio bursts. There is one point to be made about non-flare associated proton events vs far-side events – they are generally not very large.

2.2 Radio Data

After identification of the high energy proton and/or PCA event, the next problem was its correlation with a particular radio burst. In this, other aids such as flare-time information and active region history during present and earlier disk passages were used. The Imp 4 and 5, 0.5 to 1.1 MeV electron onset data and profiles were sometimes helpful since electrons (if the proton event is also an electron event), arrive rapidly in contrast to protons and tend to correlate well in time with radio burst data. Hence a radio burst or optical flare occurring at about the time of the electron event, is a good candidate for correlation with the proton event.

Ambiguity between several flare/burst candidates and proton increases was a problem at times. It was worst during sunspot maximum years and was especially acute when proton profiles appeared to be related to more than one parent event over several days. It was further compounded by the incidence of SSC effects to modulate a proton time-intensity profile. Sometimes appreciation of active region behavior relative to burst production, allowed us to make more reliable correlations than would be possible by flare data alone. For example, a given region tends to generate bursts with quite similar spectral characteristics over many hours. In some instances, we have arrived at parent event/proton event associations which are difference from those of other researchers. No doubt there are some incorrect correlations. Often, one is inclined to merely select the biggest flare nearest the time of the proton event for correlation. Clearly, the appreciation of, and use of radio data improves proton correlation studies.

As no single source of proton data was used in compiling the present list, no single source of radio data was used. The principal sources of radio data for correlation purposes were the Sagamore Hill and Manila Observatory radio data monthly listings maintained at AFGL and published in the AFCRL Geophysics and Space Data Bulletins through 1974.[21] The same data appear continuously in the NOAA Solar Geophysical Data monthly reports.[12]

The IAU Quarterly Bulletin of Solar Activity[24] through Secember 1970 was especially useful since radio burst data from many reporting observatories were listed therein with notations of flare association. The burst data from about a dozen European and Far East observatories complemented the Sagamore Hill and Manila data essentially in the microwave range.

Earlier, correlations for the years 1966-1968[19] and Appendix A of the AFCRL Geophysics and Space Data Bulletins October 1970 through December 1974,[21] wherein proton events were researched each quarter, provided a starting point for the present effort.

2.2.1 RADIO BURST CRITERIA

From the procedure followed in preparing this list, criteria are more appropriate to the proton event selection. However, in validating the solar source of >10 MeV events, we had some bias toward centimeter wavelength bursts. Furthermore, it was believed that for visible disk proton events burst flux densities $>10 \times 10^{-22}$ W m^{-2} Hz^{-1} at cm λ (even for the smallest events) should be found. Nevertheless, if no cm λ burst could be found, meter λ noise storms and dekametric sweep events were also inspected.

3. PROTON EVENTS 1966–1976

3.1 Table of Events

Table 1, the heart of the present effort, contains a list of Proton and PCA events not included in catalog I,[6] since they did not conform to the selection criteria for inclusion. The data given in the 17 columns are obvious from the column heading. Note especially that column 16 indicates "U" for tnose 4 events which should have been included in catalog I. It also indicates "0" for those 36 events for which the source was uncertain. For some, the proton increases most certainly were from far side activity. These "0"'s will be discussed more in a later section. Our main interest is necessarily in predicting principal proton/PCA events where the >10 MeV proton count exceeds 50 and where the PCA exceeds 2.0 dB.

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24. International Astronomical Union (1966-1971) Quarterly Bulletin of Solar Activity, Waldmeier Ed., published by Eidgenossische Sternwarte, Zurich.

Table 1. Comprehensi

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Ma >10 Me
1 1967	28 Jan	28/1500 1400	29/1800 29/1800	60 131	Thule McMurdo	–	–	Far Side W-150° ?	–	–	75*
2 1967	2 Feb	2/2000		130	McMurdo	–	–	Far Side ?	–	–	67*
3 1967	13 Feb 	 13/1900	 16/0200	 –	 McMurdo	4B	S 1746 M 1804	N22, W10	126°	8687	2.5*
4 1967	11 Mar	11/1900	12/1900 12/1900	25	Thule McMurdo	–	–	Far Side ?	–	–	25*
5 1967	6 Jun	6/0900	7/0200	61	Thule	SN ?	5/1950 ?	N24, E90	224° ?	8818 ?	32*
6 1967	12 Jun	–	15/1600	>78	Thule	–	–	Far Side Rgn. #8818 Nr. East Limb ?	290° ?	Return	0.9*
7 1967	5 Jul	5/~0800	6/2200	–	Shep. Bay	–	–	Far Side	–	8878 at W90 or 8863 at W129	0.9*
8 1967	18 Sept	19/0100	19/1800	65	McMurdo	2B	18/2316	N16, W60	186°	8973	3.6*
9 1967	20 Sept	–	20/1800	–	McMurdo	Many sub-flare nr. west limb; just beyond?			–	8972	6.4*
10 1967	7 Nov	–	7/0600	–	McMurdo	SN	7/0157	S15, W51	–	9047	2.5*
11 1967	13 Nov	13/0300	15/0300	–	McMurdo	SN	–	–	–	9067 ?	2.5*
12 1967	3 Dec	3/0930 –	3/1230 3/1400	–	Exp 34 McMurdo	–	–	Far Side W100 ?	–	9091 ?	~40
13 1967	16 Dec	16/0400 –	– 16/1700	40	Exp 34 McMurdo	SN	16/0247	N23, E66 Probable	339°	9118	~5.0
14 1967	17 Dec	–	 17/2100	–	 McMurdo	SN	17/1818	N19, W09	33°	9115	5.0
15 1968	2 Jan	3/1800	–	–	Exp 34	1B	2/0519 0529 0545	S22, E89	90	9145	0.4
16 1968	11 Jan	11/1830	–	8	Exp 34	1B	11/1659	S25, W38	91	9145	1.6

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I

ehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$† and Remarks
hule cMurdo	–	–	Far Side W-150°?	–	–	75*	2.7 7.0	–	–	– O	GLE
cMurdo	–	–	Far Side ?	–	–	67*	2.6	–	–	– O	–
cMurdo	4B	S 1746 M 1804	N22, W10	126°	8687	2.5*	0.5	13/1743 1804 1830	40-80	Flat	1.4 delay to onset, 1.2h delay to max, 56h
hule cMurdo	–	–	Far Side ?	–	–	25*	1.0 1.6	–	–	– O	
hule	SN?	5/1950 ?	N24, E90	224° ?	8818 ?	32*	1.8	5/1915 1951 2139	~20	Flat	0.5
hule	–	–	Far Side Rgn. #8818	290°?	Return Nr. East Limb ?	0.9*	0.3	–	–	– O	–
hep. Bay	–	–	Far Side	–	8878 at W90 or 8863 at W129	0.9*	0.3	–	–	– O	–
lcMurdo	2B	18/2316	N16, W60	186°	8973	3.6*	0.6	18/2320 18/2355 19/0320	25-75	Flat	1.7
lcMurdo	Many sub-flare nr. west limb; just beyond?			–	8972	6.4*	0.8	–	–	– O	–
lcMurdo	SN	7/0157	S15, W51	–	9047	2.5*	0.5	–	–	– O	Possible optical No radio
lcMurdo	SN	–	–	–	9067 ?	2.5*	0.5	12/1340 1350 1355	15-80	O	Very week radio or opt corr
xp 34 lcMurdo	–	–	Far Side W100?	–	9091 ?	~40	1.8	3/0854	Type II	O	
xp 34 lcMurdo	SN	16/0247	N23, E66 Probable	339°	9118	~5.0	0.8	16/0246 0252 0317	70-300	Flat	0.8
lcMurdo	SN	17/1818	N19, W09	33°	9115	5.0	0.7	17/1834 1839 1848	30-60	Flat	0.3
xp 34	1B	2/0519 0529 0545	S22, E89	90	9145	0.4	–	2/0521 0523 0534	3500	U with Type II	Belongs in Catalog I
xp 34	1B	11/1659	S25, W38	91	9145	1.6	–	11/1658 1700 1707	200-800	Weak U	–

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Table 1. Comprehensive List

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV
17 1968	8 Feb	8/1500	8/1700	12	Exp 34 McMurdo	—	—	Far Side W115°?	—	9184 ?	1.6
18 1968	17 Feb	17/0330	17/0900	24	Exp 34 Riom.	1B	17/0252	N17, W47	251°	9204	2.0
19 1968	26 Apr	26/1630 1630	26/2000 1815	33	Exp 34 McMurdo	—	—	Far Side ?	—	—	6.0
20 1968	12 Jul	12/0530 12/0600	12/0900 12/1100	—	Exp 34 Riom.	2N	12/0000	N12, E10	157°	9503	0.3
21 1968	12 Jul	12/1600 12/1930	13/2300 13/1900	—	Exp 34 Riom.	2N	12/<1348	N11, W20	170°	9499	50
22 1968	26 Jul	26/0900	26/2000	—	Exp 34	—	—	Far Side ?	—	9503 ?	0.5 —
23 1968	14 Aug	14/1600	14/1930	24	Exp 34	1B	14/1327	N13, W80	163°	9567	0.2
24 1968	28 Sept	28/1100	28/2200	—	Exp 34 McMurdo	2B	28/0721	S18, E39	228°	9692	0.6
25 1968	28 Sept	28/0800	28/2300	—	McMurdo	2B	28/0152	N13, E06	210°	9692	6.0
26 1968	4 Oct	4/0200 4/0615	4/0800 4/0900	72	Exp 34 McMurdo	2B	3/2343	S17, W36	173°	9692	30
27 1968	27 Dec	27/1400	28/0400	72	Exp 34	2B	27/1050	N16, E03	100°	9842	0.4
28 1969	24 Jan	24/0810 1400	24/1230 1700	40 19	Exp 34 McMurdo	2B	0720	N20, W09	106°	9879	3.2 —
29 1969	28 Feb	28/1300 1300	28/1600 1800	15 33	Exp 34 Riom.	SN	1231	S21, E09	346°	9957	2.0 —
30 1969	11 Apr	11/0230 11/1300	13/0300	240	Exp 34 Thule	1N	10/0410	N11, E90	75°	10035 Return of 9994	1350 —
31 1969	21 Apr	21/0100	22/0600	12	Exp 34	3B	21/2005 2011 2103	N24, W32	65°	10035	Small

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
Exp 34 McMurdo	—	—	Far Side W115°?	—	9184 ?	1.6	0.6	—	—	O	Probably beyond W. Limb., No opt or Rad.
Exp 34 Riom.	1B	17/0252	N17, W47	251°	9204	2.0	0.4	17/0250 0252 0313	—	Weak U	0.4
Exp 34 McMurdo	—	—	Far Side ?	—	—	6.0	0.5	II 26/1529- 1534	—	O	1 hr delay to P onset
Exp 34 Riom.	2N	12/0000	N12, E10	157°	9503	0.3	0.9	12/0000 0009 0023	~100	Flat	0.5. Complex period, multiple Events.
Exp 34 Riom.	2N	12/<1348	N11, W20	170°	9499	50	0.3	12/1347 1405 1434	~80	Flat	3.0
Exp 34	—	—	Far Side ?	—	9503 ?	0.5 —	—	—	—	O	—
Exp 34	1B	14/1327	N13, W80	163°	9567	0.2	—	14/1322 1338 1421	~400	Weak "A"	3.0
Exp 34 McMurdo	2B	28/0721	S18, E39	228°	9692	0.6	1.2	28/0712 0840 1310	~50	Flat	2.0
McMurdo	2B	28/0152	N13, E06	210°	9692	6.0	1.2		~75	Flat	0.8
Exp 34 McMurdo	2B	3/2343	S17, W36	173°	9692	30	1.6	3/2347 4/0010 4/0050	50-100	Flat	2.7
Exp 34	2B	27/1050	N16, E03	100°	9842	0.4	— —	27/1047 1056 1122	x = 2830	U	Belongs in Catalog I, long dur.
Exp 34 McMurdo	2B	0720	N20, W09	106°	9879	3.2 —	— 1.4	24/0705 0720 0845	~150	Flat	0.5 to 2.0
Exp 34 Riom.	SN	1231	S21, E09	346°	9957	2.0 —	— 1.0	28/1231 1237 1314	~15	Flat	0.2 or 0.8 could be from Rgn 9946 over W. limb
Exp 34 Thule	1N	10/0410	N11, E90	75°	10035 Return of 9994	1350 —	— 12-16	10/0355 10/0359 10/0414	~750	Start of U	Beyond East limb.
Exp 34	3B	21/2005 2011 2103	N24, W32	65°	10035	Small	—	21/2005 2008 2019	x = 2500	Weak U	Burst fast rise; possible for Catalog I.

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Table 1. Comprehensive List

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Ma >10 Me
32 1969	2 May	2/1950	3/0000	16	–	1B	2/1745 1752 1840	N08, W40	279°	10057	Small
33 1969	5 May	5/1320	5/1600- 2200	24	–	SN	0919 0958	N09-W73	279°	10057	Small
34 1969	13 May	13/0500	15/0000 15/0000	144	 Riom.	?	?	?	–	–	Small
35 1969	29 May	29/2114	29/2200	25	Heos P > 6 MeV	1B	1939	N10, W76	318°	10109	0.33
36 1969	25 Sept	25/0800 1000	25/1000 1300	12	Exp 41 Shep. Bay	3N	0630 0658 0753	N13, W15	130°	10326	20 –
37 1969	27 Sept	27/1000 27/0800	27/1900 27/1000	>12	Exp 41 McMurdo	3B	<0350	N09, E02	88°	10333	0.9 –
38 1969	27 Sept	27/2200	27/2400 28/0300	48	Exp 41	1N?	0326	N06, W73	155°	10325	10.0 –
39 1969	14 Oct	13/1000	14/2200	72	Exp 41	?	–	–	–	–	1.6 –
40 1969	14 Oct	14/0800	14/1100	8	Exp 41	2N	0539	N25, W71	296°	10352	3.0
41 1969	14 Oct	14/1945	14/2100	20	Exp 41	–	1847	–	–	–	1.6 –
42 1969	7 Nov	7/0830 7/1200	8/0400 8/0700	45	Exp 41 Riom.	2N ?	0320 ?	N14, E11 ?	238° ?	10406 or 10412	7.9 –
43 1969	30 Nov	–	–		Exp 41	SN	1700 1710 1727	N23, E02	318°	10447	Sporadi
44 1969	18 Dec	18/1620	18/2000	25	Exp 41 McMurdo	–	1445	Beyond NW Limb?	171° ?	–	1.5 –
45 1969	20 Dec	20/0100 20/0100	20/0500 20/0500	55 65	Exp 41		No Flare Patrol			?	8.0
46 1969	30 Dec	30/2010	31/1000	>20	Exp 41 McMurdo	1N	1927	S14, W85	219°	10491	2.0

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
—	1B	2/1745 1752 1840	N08, W40	279°	10057	Small	—	2/1748 1750 1756	~500	Medium "A"	Small event cannot predict from data
—	SN	0919 0958	N09-W73	279°	10057	Small	—	5/0935 0958 1025	~20	Flat	0.5
iom.	?	?	?	—	—	Small	1.2		—	O	Source uncertain
leos ' >6 MeV	1B	1939	N10, W76	318°	10109	0.33		29/1938 1942 1945	—	A2	0.7 Correlation probable
xp 41 hep. Bay	3N	0630 0658 0753	N13, W15	130°	10326	20 —	— 0.7	25/0630 0730 0840	~18	Flat	$<10^{-17}$
xp 41 IcMurdo	3B	<0350	N09, E02	88°	10333	0.9 —	— 0.3	27/0345 0435 0715	~80	Flat	>3.0
xp 41	1N?	0326	N06, W73	155°	10325	10.0 —	— 1.7	Uncertain 27/2059	~30	Flat	0.4
xp 41	?	—	—	—	—	1.6 —	— 0.4		—	O	Unknown CO-ROT. RGN?
xp 41	2N	0539	N25, W71	296°	10352	3.0	— 0.4	14/0540 0554 0650	~10	Flat	0.2
xp 41	—	1847	—	—	—	1.6 —	— —	14/1838 1847 1858	—	O	Possibly at W71, unknown.
xp 41 iom.	2N ?	0320 ?	N14, E11 ?	238° ?	10406 or 10412	7.9 —	— 1.4	7/0339 0345? 0348	~66	O	Uncertain source 3 possibles
xp 41	SN	1700 1710 1727	N23, E02	318°	10447	Sporadic		30/1704 1706 1720	~200	Flat O	Suspect No. 10432, two days beyond W. limb.
xp 41 IcMurdo	—	1445	Beyond NW Limb?	171° ?	—	1.5 —	— 0.6	18/1445 1515 1550	30-200	Flat	1.0
xp 41	No Flare Patrol				?	8.0	1.3	19/2335 2348 20/0025	25-100 Type II	Flat	1.3
xp 41 IcMurdo	1N	1927	S14, W85	219°	10491	2.0	0.4	30/1918 1924 1940	20-100	Flat	0.3

Table 1. Comprehensive List of 1

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Ma >10 Me
47 1970	28 Jan	28/1300	28/2400	24	Exp 41	2N	0612 0619 0646	S15, W25	293°	10542	1.0
48 1970	29 Jan	29/1300	29/2400	45	Exp 41	2B	28/1913 1930 2020	S14, W33	281°	10542	5.0
49 1970	31 Jan	31/1600	31/2400	72	Exp 41	2B	1512 1535 1816	S23, W62	285°	10542	2.5
50 1970	11 Feb	11/2000	11/2400	6	Exp 41	2B	0703 0711 0827	N18, W06	90°	10568	Small
51 1970	26 Feb	26/1400	–	24	Exp 41	–	–	–	–	–	0.2
52 1970	1 Mar	possible		–	Exp 41	1B	–	–	–	10607	Small
53 1970	5 Mar	5/1000	5/1600	–	Exp 41	1N	0411 0420 0425	S15, E77	78°	10618	Small
54 1970	6 Mar	6/1700	6/2400	–	Exp 41	1N	1321	S14, E60	77°	–	8.0
55 1970	7 Mar	7/1100 7/1200	7/2400 8/1500	36 33	Exp 41 Thule	2B	0138 0152 0331	S12, E10	120°	10618	~80 –
56 1970	12 Mar	12/1200	12/1700	18	Exp 41	2N	0306 0315 0344	S14, W46	22°	10618	0.8
57 1970	23 Mar	23/1800	23/2200	60	Exp 41 Riom.	1N	1545	N18, W62	334°	10638	8.0 –
58 1970	25 Mar	25/2000	26/1600	48	Exp 41	1B	25/1202 1226 1430	N14, E10	237°	10641	2.0
59 1970	7 Apr	7/1600	8/0100	48	Exp 41	1N	6/1948 2015 2104	S13, E32	53°	10669	0.5
60 1970	5 May	5/0400	6/1200	84	Exp 41	–	–	–	–	10725 Near E limb?	0.5
61 1970	30 May	30/0900	30/2000	60	Exp 41 Riom.	2N	30/0248 0320 0513	S06, W32	131°	10760	20 –

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
Exp 41	2N	0612 0619 0646	S15, W25	293°	10542	1.0	0.8	28/0608 0645 0710	5-25	Flat	0.5
Exp 41	2B	28/1913 1930 2020	S14, W33	281°	10542	5.0	–	28/1916 1919 1930	3-2600	A No Lows	2.0
Exp 41	2B	1512 1535 1816	S23, W62	285°	10542	2.5	0.3	31/1506 1554 1830	10-50	Flat	1.1
Exp 41	2B	0703 0711 0827	N18, W06	90°	10568	Small	–	11/0705 0707 0713	10-400	A No Lows	4.2
Exp 41	–	–	–	–	–	0.2	–	?	–	O	No Flare or Burst Candidate
Exp 41	1B	–	–	–	10607	Small	–	1/0501? or 0938 or 1109	–	Flats	$>10^{-17}$ possible Flat False Alarm
Exp 41	1N	0411 0420 0425	S15, E77	78°	10618	Small		5/0418 0445 1000	15-50	Flat	0.8 to 4.0
Exp 41	1N	1321	S14, E60	77°	–	8.0	1.0	6/1320 1324 1330	20-200	Weak Flat	Unclassified
Exp 41 Thule	2B	0138 0152 0331	S12, E10	120°	10618	~80 –	– 3.8	7/0142 0158 0222	50-100	Flat	~1.0
Exp 41	2N	0306 0315 0344	S14, W46	22°	10618	0.8	–	12/0306 0310 0416	50-100	Flat	0.7
Exp 41 Riom.	1N	1545	N18, W62	334°	10638	8.0 –	– 0.5	23/1549	10-50	Weak O	Poor candidate
Exp 41	1B	25/1202 1226 1430	N14, E10	237°	10641	2.0	–	25/1207 1220 1230	100-300	Flat	0.7
Exp 41	1N	6/1948 2015 2104	S13, E32	53°	10669	0.5		6/1922 2037	50-200	Flat	~2.9
Exp 41	–	–	–	–	10725 Near E limb?	0.5	–	–	–	O	Co-Rot. Rgn??
Exp 41 Riom.	2N	30/0248 0320 0513	S06, W32	131°	10760	20 –	– 1.9	30/0302 0341 0400	15-100	Flat	0.2

Table 1. Comprehensive List of 1

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proto Flux M >10 Me
62 1970	25 Jun	25/2300	26/1800	50	Exp 41	2B	25/1823 1838 1940	N11, E11	97°	10801	1.0
63 1970	6 July	–	6/2400	–	Exp 41	–	–	N16, W88	–	–	0.5
64 1970	7 July	7/1700	7/2300	56	Exp 41	1B	–	Beyond W. Limb?	–	10808 ?	6.0
65 1970	23 Aug	23/0500	23/1100	24	Exp 41	–	–	–	–	10882 ?	0.5
66 1970	23 Nov	23/1400	23/2100	50	Exp 41	–	?	–	–	11029 ?	0.8
67 1970	24 Dec	24/0800	24/2200	192	Exp Riom.	–	?	–	–	–	7.0
68 1971	17 Jan	17/0917	17/2000	–	Pion. 6 Exp 41	2N	16/0805 0829 1041	N19, E66	209°	11128	Small
69 1971	1 Apr	1/1600	2/1000	48	Exp 41 Riom.	1N	1/1300 1322 1422	S20, W12	29°	11221	2.5
70 1971	20 Apr	20/2200 21/0000	20/2400 21/0800	30 10	Exp 41 Thule	2B	20/0513 0522 0612	N20, W20	151°	11256	2.6
71 1971	22 Apr	22/1200	22/1900	40	Exp 40	1B	20/1924 1946 2141	S06, W50	145°	11250 ?	2.0
72 1971	12 May	12/0400	12/0700	24	Exp 41	2N	21/0131 0201 0322	N15, W73	274°	11294	0.3
73 1971	13 May	13/1930	14/0200	18	Exp 41	1N	13/1751 1758	N11, W86	266°	11294	0.3
74 1971	14 May	14/1500	14/2400 16/1800	48	Exp 41 Riom.	1N	14/0847 0902 0921	N05, E42	130°	11313	0.3
75 1971	16 May	16/1300	17/0400	36	Exp 41	–	–	N11, W125 ?	–	11294 ?	10.0 –
76 1971	30 Jun	30/0600	30/1000	18	Exp 41	SB	29/2235 2248 2303	N17, W22	284°	11393	0.5

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

on	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
	Exp 41	2B	25/1823 1838 1940	N11, E11	97°	10801	1.0	0.8	25/1833 1837 1920	25-100	Flat	1.0
	Exp 41	—	—	N16, W88	—	—	0.5	—	—	—	— O	—
	Exp 41	1B	—	Beyond W. Limb?	—	10808 ?	6.0	—	7/0537 0538 0541	—	C	West Limb?
	Exp 41	—	—	—	—	10882 ?	0.5	—	22/0044 0051 0120	50-150	Flat	0.7
	Exp 41	—	?	—	—	11029 ?	0.8	—	—	—	O	Beyond W. limb?
	Exp Riom.	—	?	—	—	—	7.0	0.6	24/0340 0430 0620	10-25	Flat	0.7
	Pion. 6 Exp 41	2N	16/0805 0829 1041	N19, E66	209°	11128	Small	—	16/0802 0828 0850	300-500	Flat	4.5
	Exp 41 Riom.	1N	1/1300 1322 1422	S20, W12	29°	11221	2.5	0.4	1/1245 1325 1535	15-150	Flat	0.8
	Exp 41 Thule	2B	20/0513 0522 0612	N20, W20	151°	11256	2.6	0.9	20/0512 0518 0520	1800 at x	A	Unusual event
	Exp 40	1B	20/1924 1946 2141	S06, W50	145°	11250 ?	2.0	–	20/1916 1950 2040	20-40	Flat O	0.75 Uncertain corr.
	Exp 41	2N	21/0131 0201 0322	N15, W73	274°	11294	0.3	— —	12/0143 0200 0216	50-400	Flat	1.2
	Exp 41	1N	13/1751 1758	N11, W86	266°	11294	0.3	—	13/1750 1920 2050	50-250	Flat	5.0
	Exp 41 Riom.	1N	14/0847 0902 0921	N05, E42	130°	11313	0.3	0.6	14/0817 0823 0845	40-120	Flat	0.35
	Exp 41	—	—	N11, W125 ?	—	11294 ?	10.0 —	— 1.3	?	?	O	Beyond W. limb?
	Exp 41	SB	29/2235 2248 2303	N17, W22	284°	11393	0.5	—	29/2236 2238 2243	150-400	Flat	—

Table 1. Comprehensive List of

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV
77 1971	21 Aug	—	21/1600	—	ATS-1	1B	21/0932 0936 0949	S09, E25	276°	11482	<1.0
78 1971	1 Sept	1/2000 1/2200	2/0800 1000	240	Exp 41 Thule	?	?	W120° ?	268° ?	11482 ?	~350
79 1971	15 Sept	—	15/1000	—	ATS-1	SN	0320 0328 0434	S12, E53	181°	11516	Small
80 1971	25 Sept	25/1200	25/1400	9	ATS-1	SN	24/0442 0458 0537	N17, W82	284°	11514	Small
81 1971	3 Oct	3/1700	4/1400	72	Exp 41	1B	3/1313 1348 1445	N13, E14	77°	11537	3.2
82 1971	24 Nov	23/1000	24/1600	36	Exp 43	1B	23/0536 0608 0619	S16, E60	70°	11619	0.3
83 1971	2 Dec	2/0300	2/0700	18	Exp 43 McMurdo	1B	2/0110 (2 Flares)	S15, W66	91°	11619	1.0
84 1971	14 Dec	14/0400	17/0200 17/0800	168	Exp 43 Thule		Far Side	?	?	?	4.0
85 1971	29 Dec	30/0500	30/0500	18	ATS-1 Riom.	1N	—	S21, W74	—	11657	4.8
86 1972	3 Jan	3/0800	4/0200	120	Exp 43	?	?	?	—	?	0.5
87 1972	10 Jan	10/1900	11/0400	72	Exp 43	?	?	?	—	?	1.1
88 1972	16 Jan	16/0200	17/2000	26	Exp 43	1N	16/1745 1836 2032	S12, E70	74°	11693	0.3
89 1972	19 Jan	19/2300 20/1500	20/2300 21/1100	96 38	Exp 43 Thule	1B	19/1639 1644 1716	S16, E13	93°	11693	20 —
90 1972	11 Mar	11/1600	11/2400	24	Exp 41	SN	10/2228 2230 2234	S16, W32	170°	11769	0.2

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

Vehicle or Site	Flare Imp.	Flare Timing UT	Flare Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
ATS-1	1B	21/0932 0936 0949	S09, E25	276°	11482	<1.0	—	21/0933 0934 1010	150-400	Flat	0.7
Exp 41 Thule	?	?	W120° ?	268° ?	11482 ?	~350	— 5.2	1/1934 1941 2010	—	—	—
ATS-1	SN	0320 0328 0434	S12, E53	181°	11516	Small	—	15/0319 0326 0339	30-60	Flat	1.3
ATS-1	SN	24/0442 0458 0537	N17, W82	284°	11514	Small	—	24/0440 0500 0730	20-40	Flat	0.4
Exp 41	1B	3/1313 1348 1445	N13, E14	77°	11537	3.2	—	3/1336 1346 1500	40-90	Flat	>2.0
Exp 43	1B	23/0536 0608 0619	S16, E60	70°	11619	0.3	—	23/0545 0552 0645	~200	Flat	1.1
Exp 43 McMurdo	1B	2/0110 (2 Flares)	S15, W66	91°	11619	1.0	0.7	2/0100 0320 0440	150-600 2 Bursts	Flat	9.0
Exp 43 Thule		Far Side	?	?	?	4.0	1.9	14/0240 0250 0310	—	— O	Return to E. limb of rgn. 11619 due 17 Dec.
ATS-1 Riom.	1N	—	S21, W74	—	11657	4.8	0.7	29/2312 2313 2330	50-600	Weak C	0.9
Exp 43	?	?	?	—	?	0.5	—	—	—	O	Possibly rgn. No. 11657 No. 11657 behind W. limb.
Exp 43	?	?	?	—	?	1.1	—	—	—	O	Far side?
Exp 43	1N	16/1745 1836 2032	S12, E70	74°	11693	0.3	—	15/1757 1816 1950	~35	Flat	1.0
Exp 43 Thule	1B	19/1639 1644 1716	S16, E13	93°	11693	20 —	— 1.8	19/1618 1645 1720	10-40	Flat	1.0
Exp 41	SN	10/2228 2230 2234	S16, W32	170°	11769	0.2	—	10/2228 2229	—	Weak U	0.2 Co-rot. rgn? No. 11724?

Table 1. Comprehensive List c

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux M >10 Me
91 1972	28 Mar	28/0800	28/1200	18	Exp 41	–	–	–	–	–	0.7
92 1972	18 Apr	18/0300	18/0500	120	Exp 41	–	–	–	–	–	20
93 1972	26 Apr	26/1200	26/2100	48	Exp 41 Riom.	–	–	–	–	–	0.2
94 1972	8 Jun	8/1600	9/0600	120	Exp 41	–	–	–	–	–	10.0
95 1972	14 Jun	14/1400	17/1200		Exp 41 Thule		15/1249 1313 1450	S14, W01	315°	11922	20
96 1972	19 Jul	19/0700	19/2200	72	Exp 41	–	–	–	–	–	3.0
97 1972	22 Jul	–	22/1200 22/1600	–	Exp 41 Thule	–	–	–	–	–	6.0
98 1972	22 Jul	22/0100	28/2100	–	Exp 41	–	–	–	–	–	8.8
99 1972	16 Aug	15/0300	16/2300	50	Exp 41	–	–	–	–	–	5.0
100 1972	6 Sept	2/2200	7/0500	30	Exp 43	1N	5/1428 1434 ? 1521 ?	S24, W21 ?	317° ?	12014 ?	1.0
101 1972	29 Oct	29/2010	30/0100	–	Exp 41	2N	29/1544 1747 2020	S10, E05	311°	12094	2.0
102 1972	17 Nov	?	17/1600	30	Exp 41	–	?	?	–	–	0.4
103 1972	25 Nov	25/1200	25/1600	20	Exp 41	1B	25/0820 0830 0911	S06, W44	7°	12115	0.5
104 1972	28 Nov	28/0600	28/1100	24	Exp 41	1N	28/0355 0403 0426	S08, W80	7°	12115	0.5
105 1972	16 Dec	16/0700	16/1700	36	Exp 41	1B	15/0539 0551 0644	S06, E47	2	12143	0.3
106 1973	1 Mar	–	–	–	–	1B	1/1115 1122 1204	N08, W07	145°	12246	–

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 MeV	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
Exp 41	–	–	–	–	–	0.7	–	–	–	O	Far side? 11769 behind E. limb?
Exp 41	–	–	–	–	–	20	1.6	–	–	O	Far side? No. 11813?
Exp 41 iom.	–	–	–	–	–	0.2	0.6	–	–	O	Far side? 11813?
Exp 41	–	–	–	–	–	10.0	–	–	–	O	Far side? No. 11895 at W110?
xp 41 hule		15/1249 1313 1450	S14, W01	315°	11922	20	2.7	15/1236 1336 1510	25-50	Flat	1.2 to 2.4
xp 41	–	–	–	–	–	3.0	–	–	–	O	Far side?
xp 41 hule	–	–	–	–	–	6.0	0.6	–	–	O	Far side? Rgn 11976?
xp 41	–	–	–	–	–	8.8	–	–	–	O	Far side?
xp 41	–	–	–	–	–	5.0	–	–	–	O	Far side of 11976? Or Co-Rot. 11895?
xp 43	1N	5/1428 1434? 1521?	S24, W21 ?	317° ?	12014 ?	1.0	–	5/1415 1530 2200	~10	Flat	1.0 Very uncertain
xp 41	2N	29/1544 1747 2020	S10, E05	311°	12094	2.0	–	29/1553 1652 ~1900	40-65	Flat	3.0 Av
xp 41	–	?	?	–	–	0.4	–	–	–	O	No Flare or burst candidate.
xp 41	1B	25/0820 0830 0911	S06, W44	7°	12115	0.5	–	25/0819 0846 1009	100-160	Flat	1.0
xp 41	1N	28/0355 0403 0426	S08, W80	7°	12115	0.5	–	28/0400 0410 0415	10-25	Flat	0.3
xp 41	1B	15/0539 0551 0644	S06, E47	2	12143	0.3	–	15/0536 0541 0636	65-80	Flat	0.6 Possible flare 0338.
–	1B	1/1115 1122 1204	N08, W07	145°	12246	–	–	1/1116 1120 1152	–	U	False Alarm with Type II. No protons.

Table 1. Comprehensive List

Event No., Year	Date Proton Start	UT Proton Start	Proton Max	Duration hours	Vehicle *or* Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Pr Flu >10
107 1973	11 Apr	12/1000	12/1600	48	Exp 43	1B	11/2017 2024 2104	S12, W07	320°	12306	(
108 1973	16 Jun	–	–	–	–	2B	16/1419 1427 1513	N13, E11	153°	12387	Sr
109 1973	26 Jun	–	–	–	–	1B	26/0157 0159 0404	S08, W27	64°	12397	Sr
110 1973	29 Jul	–	–	–	Riom.	2N	29/1310 1323 1335	N15, E45	270°	12461	Sr
111 1973	7 Sept	7/1245	7/1620 7/1630	–	NOAA 2&3 Thule	2B	7/1143 1202 1300	S18, W46	192°	12507	2
112 1973	3 Nov	3/0600	–	–	–	2N	3/0012 0034 0101	S18, W85	206°	12584	Sr
113 1974	30 Jun		Suspect protons			–	30/2223 2247 2316	S12, E47	149°	13043	
114 1974	13 Sept	–	–	–	NOAA 2&3	1B	13/1458 1515 1758	N12, E20	268°	13225	nc
115 1974	23 Sept	23/2200	24/2200		NOAA 2&3	–	–	–	–	13225 ?	(
116 1974	15 Oct		No Proton Data		Riom.	1B	15/1325 1326 1329	N06, W43	269°	13280	
117 1975	17-21 Nov		Trace	–	–	–	–	?	–	–	
118 1976	28 Mar	–	—	–	–	1B	28/1905 1921 2017	S07, E28	44°	14143	Su

* = calulated from $P = 10\ A^2$

Sfu = $1 \times 10^{-22}\ w\ m^{-2}\ Hz^{-1}$

† Flux $\times 10^{-17}$ = $10^{-17}\ J\ m^{-2}\ Hz^{-1}$

Table 1. Comprehensive List of 118 Proton Events 1966-1978 Not Found in Catalog I (Cont.)

Vehicle or Site	Flare Imp.	Flare Timing UT	Flare-Burst Disk Pos.	Carrington Long.	McMath No.	Proton Flux Max >10 Mev	PCA dB	Burst Timing UT	Burst Max (Sfu.)	Radio Spectrum	Integrated Radio Flux $\times 10^{-17}$ and Remarks
Exp 43	1B	11/2017 2024 2104	S12, W07	320°	12306	6.0	—	11/2021 2033 2105	30-100	Flat	0.3
—	2B	16/1419 1427 1513	N13, E11	153°	12387	Small	—	16/1417 1430 1530	25-75	Flat	0.6
—	1B	26/0157 0159 0404	S08, W27	64°	12397	Small	—	26/0132 0142 0210	200-500	Flat	2.2 to 5.0
Riom.	2N	29/1310 1323 1335	N15, E45	270°	12461	Small	<0.5	29/1310 1330 1210	25-200	Flat	1.5-3.0
NOAA 2&3 Thule	2B	7/1143 1202 1300	S18, W46	192°	12507	26? —	— 0.9	7/1139 1150 1450	40-300	Flat	1.5-2.5
—	2N	3/0012 0034 0101	S18, W85	206°	12584	Small	—	3/0011 0018	~300	Flat	1.5-5.0
	—	30/2223 2247 2316	S12, E47	149°	13043	—	— —	30/2223 2225 2233	—	U	Should have been in Catalog I.
NOAA 2&3	1B	13/1458 1515 1758	N12, E20	268°	13225	ncrease	—	13/1456 1527 1720	50-300	Flat	~4.0
NOAA 2&3	—	—	—	—	13225 ?	6.0	—	23/1158 1201 1310	—	indet	6.5 Far side?
Riom.	1B	15/1325 1326 1329	N06, W43	269°	13280	—	>0.5	15/1323 1326 1435	—	A_3	3.0-4.0
—	—	—	?	—	—	—	—	?	—	Flat	—
—	1B	28/1905 1921 2017	S07, E28	44°	14143	Suspect	—	28/1914 1929 1955	—	Flat	16.0

3.2 Prediction Findings

3.2.1 SUMMARY OF PREDICTIVE RESULTS OF CATALOG I AND THE PRESENT PAPER RELATIVE TO FALSE ALARMS

To the 81 U-shape spectra of catalog I,[6] we must add four more, Nos. 15, 27, 106 and 113 found here in Table 1 which were accidentally omitted from the earlier work. Of these, events No. 15 on 2 January 1968 and No. 27 on 27 December 1968 were associated with small proton events. Two other U-shape radio events, No. 106 and No. 113, occurred on 1 March 1973 at about 1120 UT and on 20 June 1974 at about 2225 UT respectively. Unfortunately, at the moment, both of these events must be classified "false alarms" until proven differently by additional particle information. Already the event on 23 March 1976 from catalog I originally called a possible "false alarm" was found to have proton association from Helios 2 measurements. It is also most probable that No. 113, the 30 June 1974 event at E47^{O} in McMath No. 13043 found in the present Table 1 had particle association, We suspect this in view of the tremendous amount of proton activity associated with this region for the next ten days in early July 1974. The 1 March 1973 burst at 1120 UT was a disappointment in view of the favorable disk location and the additional evidence of type II bursts. Considering the three events listed above, burst integrated flux densities at centimeter wavelengths varied between 1.5 and 2.5×10^{-17} J m^{-2} Hz^{-1} which would suggest >10 MeV proton flux of <1.0 P cm^{-2} sec^{-1} str^{-1} — very small indeed.

3.2.1.1 Misses of Proton Events

(1) Indeterminate or Far Side Sources

In Table 1, discounting the 4 additional U's, there are 114 "events." More precisely, there are 114 periods of time (of different durations) when the measured proton flux at energies greater than 10 MeV exceeded the normal background. Since the basic objective of the work is to develop a scheme by which we could have predicted the occurrence of these "events" from radio burst data, we tacitly ignore other causes and circumstances which are indeed very real causes of proton increases but which are not within the scope of radio burst prediction studies. We are not prepared to cope with these other causes here, yet they must be noted since they impact on the statistical validity of the effort. Briefly, some sources of proton flux increase other than visible disk flare/burst happenings are, for example, co-rotating proton emitting regions, storm sudden commencements, and far side (of the sun) outbursts.

In Table 1 there are 36 "0" events listed separately in Table 2 for which no reliable flare/burst candidate was found. It is assumed that many of these were caused by far side outbursts. Only two of the events, No. 1 (7 dB), and No. 2 (2.6 dB), could be called principal events which would impact on military operations.

Table 2. Thirty-six "0" Events With Unknown Source ("0" from Table 1)

Event No.	P	dB	
1	79	7	GLE, Far Side
2	67	2.6	Far Side
4	10	1.6	
6	0.9	0.3	
7	0.9	0.3	
9	6.4	0.8	
10	2.5	0.5	
11	2.5	0.5	
12	40	1.8	Far Side W100°?, No. 9091
17	1.6	0.6	
19	6.0	0.5	
22	0.48		
34	sm	1.2	
39	1.6	0.4	
41	1.6		
42	7.9	1.4	
43	sm		
51	0.2		
57	8.0	0.5	
60	0.5		
63	0.5		
66	0.8		
71	2.0		
75	10		No. 11294, Far Side
84	4.0	1.9	
86	0.5		
87	1.1		
91	0.7		
92	20	1.6	No. 11813, Far Side
93	0.2	0.6	
94	10		No. 11976, Far, near East limb
96	3.0		
97	6.0		
98	8.8		
99	5.0		
102	0.4		
36 Events Total			

Number 1 on 28 January 1967 was a Ground Level Event (GLE) and may have been triggered by a flare as far west as 150°. Obviously, there would be no optical or radio correlation. Hence, assuming a broad similarity in sunspot cycles, there may be – in a given sunspot cycle – a few very large events for which no warning, based on current usage of radio data, will be possible. Still, these can hardly be called "misses" if prediction is to be based on visibility.

All of the remaining 34 of the 36 unknowns had absorptions less than 1.8 dB and less than 40 protons at $E > 10$ MeV. The five largest events ($P > 10$ MeV with count 10-40 P) Nos. 4, 12, 75, 92 and 94 with P = 10, 40, 10, 20 and 10 respectively, most probably were caused by far side activity. All others in this group had proton counts less than 10. Because of their smallness and uncertain origin, they do not merit further attention.

There were two events not on the list of 36 referred to above (their source was partially obscured) which were principal proton events. These events were No. 30 on 11 April 1969 and No. 78 on 1 Sept 1971. The former at about $E90^{\circ}$ produced 12 to 16 dB absorption (most formidable), and the latter with 5.2 dB and also a GLE, was apparently triggered by a flare/burst beyond the west limb. For these two events, sufficient radio emission was detected to enable identification of the probable cause, but attenuation etc., precluded observation of the true predictive emission spectrum. It would also be unwarranted to call these events radio "misses," since they were not totally visible even though particles impacted severely on AF operations.

(2) True "Misses" of Principal Events

Of the remaining 76 events found in Table 1, "misses" by the U-shape criteria, only three had PCA's >2.0 dB. These were No. 21 on 12 July 1968 at $W20^{\circ}$ with 3.0 dB, No. 55 on 7 March 1970 at $E10^{\circ}$ with 3.8 dB, and No. 95 on 14 June 1972 at $W01^{\circ}$ with 2.7 dB absorption at 30 MHz. All of these events were associated with radio bursts which as a class have fairly long duration, say approximately 1 hr or longer; the emission is broadband over 1000 MHz or more, the spectrum is reasonably flat between 1000 and 9000 MHz with peak flux density around 100×10^{-22} W m^{-2} Hz^{-1}. The burst integrated flux density at any single cm wavelength is on the order of 0.5 to 1×10^{-17} J m^{-2} Hz^{-1}. (From statistics of many events, one might expect a >10 MeV proton flux of only ~ 1 proton cm^{-2} sec^{-1} str^{-1} for 1×10^{-17} J m^{-2} Hz^{-1} integrated flux density.) These 3 events were not "blockbusters." We would like to have predicted them, but could not by the U-shape spectrum criteria. If all events were routinely tested by criteria developed from the burst characteristics shown above, probably they could have been predicted.

In regard to the delay from burst max to proton onset and proton max, the three events were similar with delays to first onset of 6, 9 and 11 hr, respectively.

The delay to proton max was about 1.5 to 2 days. We shall discuss delay times later.

(3) The 73 Events With Position-Identified Flare Association

Of this group of 73 "events" with flare association, the distribution according to peak proton flux is given in Table 3.

Table 3. Seventy-three Events With Position-identified Flare Association

>10 MeV Flux Count	Number of Events
<1.0	33*
1.0- 1.9	8
2.0- 2.9	7
3.0- 3.9	5
4.0- 4.9	1
5.0- 9.9	12
10 -14.9	1
15 -19.9	0
20 -24.9	2
25 -29.9	2
30 -34.9	2
	73 Total

*Assume all events with P too small for quantitative data have $P < 0.2$.

Since an enhancement of $P < 1.0$ is probably much too small for even moderate geophysical effects impacting on Air Force operation, the top 33 events in Table 3 can be discounted. This leaves only 40 events from this group worth studying for spectrum and "delay to onset" characteristics (Table 5). Thirty-two of these events are included in Table 4.

Among these 32 events (for which we have polar cap absorption data), the absorption ranges between 0.2 and 2.0 dB. The distribution of these events is shown in Table 4.

Taking the 32 events for which we have dB values at 30 MHz, we arrive at a dB mean of 0.915, that is, $\Sigma dB/32 = 0.915$ dB.

For these same 32 events the mean proton flux, $E > 10$ MeV = 8.2, that is $\Sigma P/32 = 8.2$.

Table 4. Distribution of 32 PCA Events According to Absorption

dB Range	Number of Events	Actual Absorption
<0.19	0	
0.2-0.39	2	0.3, 0.3,
0.4-0.59	5	0.4, 0.4, 0.4, 0.4, 0.5
0.6-0.79	8	0.6, 0.6, 0.6, 0.6, 0.7. 0.7, 0.7, 0.7,
0.8-0.99	6	0.8, 0.8, 0.8, 0.9, 0.9, 0.9,
1.0-1.19	2	1.0, 1.0,
1.2-1.39	3	1.2, 1.2, 1.3,
1.4-1.59	1	1.4,
1.6-1.79	2	1.6, 1.7
1.8-1.99	3	1, 8, 1.8, 1.9
	32	

From these two values one arrives at an average relationship between >10 MeV proton flux and dB absorption where $P \simeq 9.1A^2$.

This comparies favorably with the relationship sometimes used where $P = 10A^2$.

4. DISTRIBUTIONS

Burst distributions are considered according to Carrington longitude and East-West disk position. The distributions are also compared for catalog I and II events.

4.1 Carrington Longitude

Figure 1 shows the Carrington longitude distribution of the proton events 1966-1976 in catalogs I and II. Though the radio burst intensities, the burst spectra and the proton event fluxes are quite different for events found in the separate catalogs, the distributions are very similar. The 150^o-180^o region is the most productive while the 300^o-360^o region is the quietest. After a flare/burst position-productivity pattern is established early in a sunspot cycle, the pattern information could be helpful in predicting proton events for the remainder of the sunspot cycle. We have reviewed proton data for earlier sunspot cycles and found, as have other researchers, that the Carrington longitude distribution of proton events appears to change from one sunspot cycle to the next.

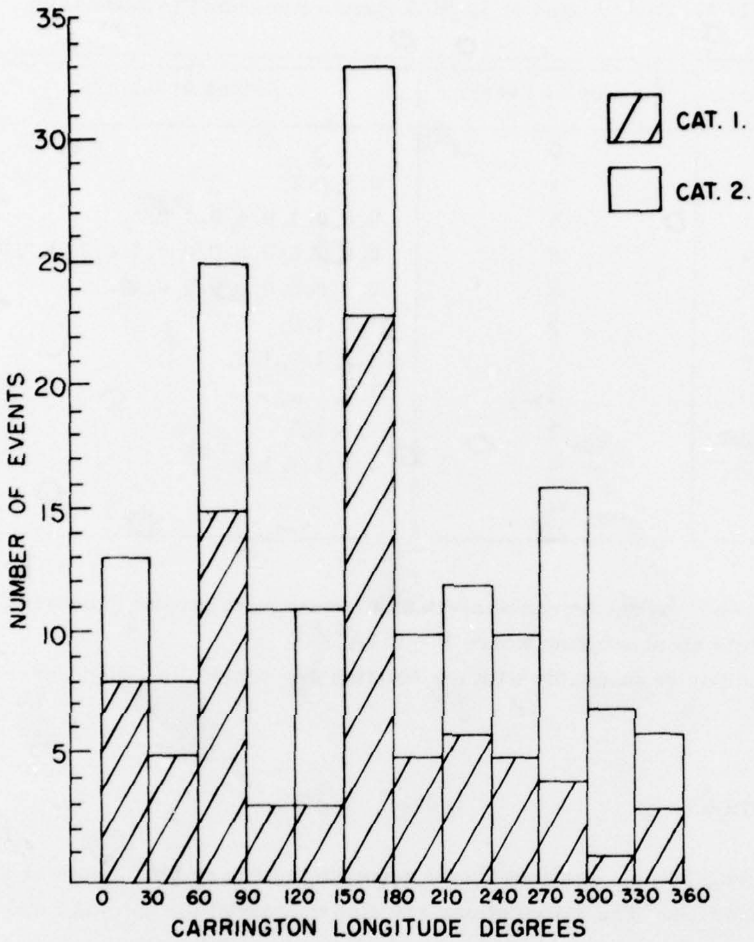

Figure 1. Sunspot Cycle No. 20 Proton Source Distribution According to Carrington Longitude

4.2 Distribution of Proton Events by Solar Longitude

Earlier studies by one of the authors reveal a fairly uniform distribution of flares across the solar disk except for the E90^{o}-E60^{o} region. Microwave bursts, especially at the higher frequencies show no preference for West vs East solar longitudes, though there are attenuation effects approaching the limbs, especially at longer wavelengths. The distribution of proton events is another matter. There is a definite E-W asymmetry of proton flare/bursts. Researchers in the cosmic

ray area are, for example, agreed[25,26] on the point. However, the asymmetry is not overwhelming. In the present study it was found that 60 percent of the events in Table 1 were from West sources. In catalog I,[6] the distribution was 57 percent from West sources with ground Level Events (GLE's) almost universally favoring the western hemisphere. In an earlier investigation covering the 19th cycle and part of the 20th, Smart et al[27] found 62 percent of the events in the Western hemisphere.

These combined statistics are shown in Figure 2. The lower profile shows the solar disk longitude proton event distribution derived from Smart et al.[27] The upper profile shows the distribution for all proton events listed in catalog I and the present work. The agreement between the two profiles is quite good. It is also apparent from the figure that the region 30°-60°W is associated with the greatest percentage of proton events for any 30°sector. Smart et al had 25 percent, whereas the present authors found 23 percent. It can be concluded that these findings have predictive merit and are in agreement with currently accepted findings. Moreover, the tendency noted does not seem to change with sunspot cycle.

The distribution of all proton events (catalog I and II) for 1966-1976 is shown in Figure 3.

4.3 Delay to First Onset and to Proton Max

In Section 3(3), we referred to 40 events for special study. These are listed in Table 5. Note that column 5 gives the earliest reported >10 MeV Proton or PCA onset elapsed time from centimeter burst max. (Remember in all this, we are evaluating the >10 MeV protons.) Column 7 lists the longest duration data reported. Column 8 gives the range of centimeter wavelength flux densities for the event. Column 9 gives the burst integrated flux density, generally at 8800 MHz, while column 10 gives a brief notation on the radio peak flux spectrum. The same parameters of catalog I events were investigated for comparison. The purpose is to determine whether there is a significant difference in delay times for the two groups which have very different radio burst characteristics. The results are shown below in Table 6. It is also convenient to compare particle event durations in the same table.

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25. Pomerantz, M.A., and Duggal, S.P. (1974) The sun and cosmic rays, Reviews of Geophysics and Space Physics, 12(No. 3):343-361.
26. Sakurai, K. (1974) Energetic Particles from the Sun, Astrophysics and Space Science, D. Reidel Pub. Co., 28, pp. 375-519.
27. Smart, D.F., Shea, M.A., Dodson, H.W., and Hedeman, E.R. (1976) Distribution of Proton Producing Flares Around the Sun, Space Research XVI, Akademie-Verlag, Berlin, pp. 797-802.

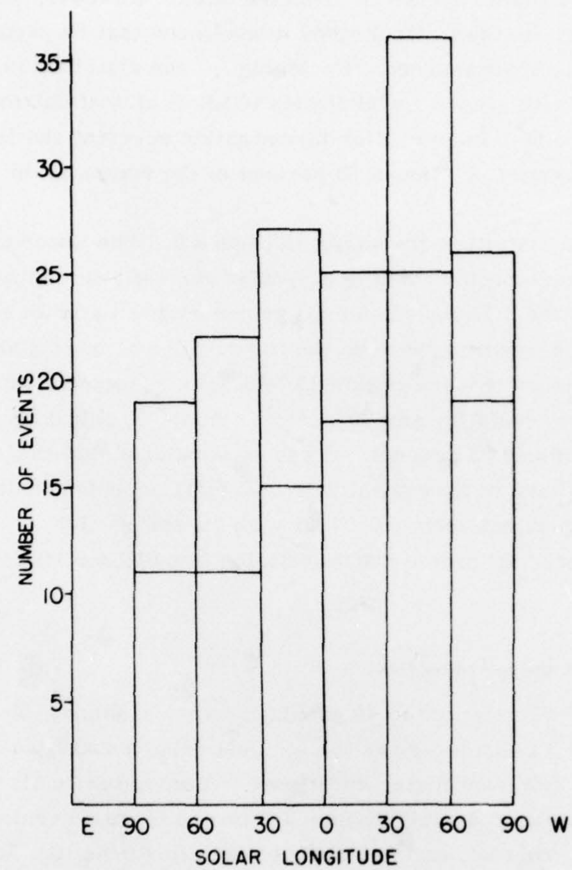

Figure 2. Distribution of Proton Events 1966-1976 From Catalogs I and II (Upper Profile), Compared With 1955-1969 PCA's From Smart et al,[27] (Lower Profile)

Whereas Figure 2 has shown the frequency of occurrence of proton events is somewhat solar longitude dependent, comparison of Columns 1 and 2 of Table 6 shows that flight time of >10 MeV protons from the source to the earth is also somewhat longitude dependent, in agreement with Reinhard and Wibberenz,[28] Ma Sung[29] and others. From Table 6, however, it appears that there are other

28. Reinhard, R., and Wibberenz, G. (1974) Propagation of Flare Protons in the Solar Atmosphere, Solar Physics, 36, pp. 473-494.

29. Sung, L. S. Ma. (1977) A Study of the Propagation and Intrinsic Characteristics of Flare Associated Particle Events, *NASA GSFC rpt No. X-660-77-1113.*

Table 5. Working Data for 40 Events; Proton Flux >1.0, <40

Event No. from Table 1	Peak Flux P > 10 MeV	PCA dB	Disk Position	Earliest Delay to Onset (hr)	Delay to Event Max (hr)	Longest Duration (hr)	Max cm Flux $\times 10^{-22}$	Burst Integ Flux $\times 10^{-17}$	Spectrum
3	2.5	0.5	W10	1.2	56	–	40-80	1.4	Flat
5	32.4	1.8	E90	13	30	61	~15	0.5	Flat
8	3.6	0.6	W60	2	18	65	25-75	1.7	Flat
13	5.0	0.8	E66	2	14	40	70-200	0.8	Flat
14	5.0	0.7	W09	3	–	–	30-60	0.2	Flat
16	1.6	–	W38	1.5	–	8	200-800	–	Weak U
18	2.0	0.4	W47	1	7	24	–	0.4	Weak U
20	0.3	0.9	E10	5.5	9	–	~100	0.5	Flat
24	6.0	1.2	E39	3	15	–	~50	2.0	Flat
25	6.0	1.2	E06	6	21	–	~75	0.8	Flat
26	30	1.6	W36	1.2	9	72	50-100	2.7	Flat
28	3.2	1.4	W09	1.0	5	40	~150	2.0	Flat
29	2.0	1.0	E09	0.5	3.5	33	~15	0.2	Flat
36	20	0.7	W15	1.0	3.5	12	~18	0.8	Flat
37	0.9	0.3	E02	6.0	15	>12	~80	3	Flat
38	10	1.7	W73	1.1	3.0	48	~30	0.4	Flat
40	3.0	0.4	W71	2.2	8.0	8	~15	0.3	Weak
44	1.5	0.6	>W90	1.1	5.0	25	30-200	1.0	Flat
45	8.0	1.3	–	1.2	5.2	65	25-100	1.3	Flat
46	2.0	0.4	W85	1.0	14	>20	20-100	0.3	Flat
47	1.0	0.8	W25	6.0	17	24	5-25	0.5	Flat
48	5.0	–	W33	17	29	45	3-2600	2	A, '
49	25	0.3	W62	1.0	8.0	72	10-50	1.1	Flat
54	8.0	1.0	E60	4.0	11	–	20-100	Small	Weak
58	2.0	–	E10	8.0	28	48	100-300	0.7	Flat
61	20	1.9	W32	5.5	16	60	15-100	0.3	Flat
62	1.0	0.8	E11	4.5	24	50	25-100	1.0	Flat
64	6.0	–	>W90	11	17	56	Small	Small	C
67	7.0	0.6	–	3.5	16	192	10-25	0.7	Flat
69	2.5	0.4	W12	2.7	21	48	15-150	0.8	Flat
70	2.6	0.9	W20	16	19	30	1800 at x		A, '
74	0.3	0.6	E42	7.0	15	48	40-120	0.4	Flat
81	3.2	–	E14	3.5	24	72	40-90	2.0	Flat
83	1.0	0.7	W66	1.0	4	18	150-600	9.0	Flat
85	4.8	1.9	W74	5.8	6	18	50-600	0.9	C
89	20	1.8	E13	6	17	96	10-40	1.0	Flat
101	2.0	–	E05	3.5	8.0	–	40-65	3.5	Flat
107	6.0	–	E47	15	35	36	65-80	0.6	Flat
111	26	0.9	W47	1.5	5.0	–	40-200	2.0	Flat
115	6.0	–	–	9.0	34	–		Indeterminate	
Average				46.5	15	46		1.3	

factors relating to the delay to onset. Note that in Table 6 Column 1, catalog I events have on an average a delay to first onset almost 1 hr shorter than catalog II events regardless of disk position. Note also that considering only the W20-W90 longitude region catalog I delay time, on an average, is very much shorter than the catalog II delay time. This suggests an overall energy dependence. The average delay time from the centimeter max to protor max is also shorter for catalog II events in comparison with catalog I; 15 hr vs 22.5 hr. The average duration is shorter too, as might be expected; 46 vs 80 hr. We do not have an exact figure for the average burst integrated flux density for catalog I events, though it appears to be on the order of 30×10^{-17} J m^{-2} Hz^{-1}. For catalog II, the average value from Table 5 is 1.3×10^{-17} J m^{-2} Hz^{-1}.

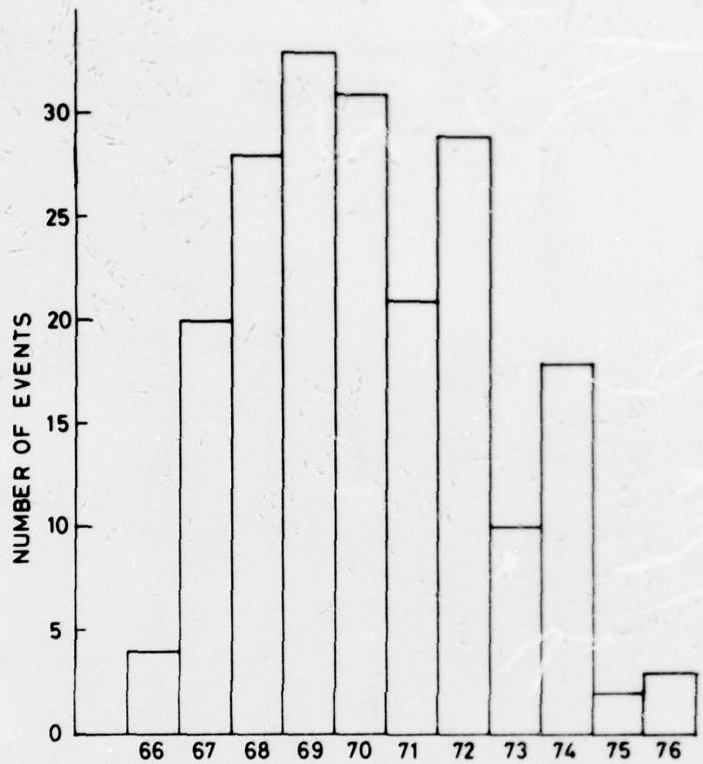

Figure 3. Distribution of Proton Events (Catalogs I and II) 1966-1976

Table 6. Average Delay to Onset in Hr

	Av. Delay to Onset E90-W90 (hr)	Av. Delay do Onset W20-W90 (hr)	Av. Delay to Max P E90-W90 (hr)	Av. Duration (hr)	Spectrum
Catalog 1	3.9	1.55	22.5	80	U
Catalog 2 (present)	4.65	4.0	15	46	Flat

5. DISCUSSION AND CONCLUSION

The basic justification for advancing correlation studies between solar particles and radio emission, is that the solar burst energy must be related to the number of electrons in the volume of solar atmosphere where the burst occurs. This should be proportional to the number of protons accelerated. The number of protons observed in space does not account for those trapped. The fact that there is any quantitative relation between protons measured and radio burst integrated flux density[30] indicates that there is a ratio which is more or less reliable. The actual solar burst intensity and particularly the spectrum relates to the energy of the causative electrons.

Both types of spectrum, the U-shape (catalog I) and the flat spectrum (catalog II) are valid types. The U-shape with which all the important proton events and many of the smaller ones are associated is consistent with a two source mechanism by the gyro-synchrotron process. This spectrum with intensities required (statistically) for proton emission is indicative of particles accelerated to high energies in the source. The width of the U especially, and the spectral slope above f_{max} have been correlated with the observed proton spectrum[31] and is reliable enough for proton energy prediction.

The flat spectrum which describes the radio signature of catalog II events is also recognized as a spectral type.[26, 32, 33] While bursts with this type spectrum are not common, it can not be said that the flat spectrum is limited to weak proton events. Ramaty and Petrosian[33] concluded that bursts whose spectra were essentially flat in the 2,000 to 20,000 MHz range could not be produced by thermal emission unless the flux densities were less than about 50 sfu (10^{-22} W m^{-2} Hz^{-1}), but could be caused by free-free absorption of non thermal gyrosynchrotron emission. They would require an electron density of $\sim 2 \times 10^{10}$ cm^{-3}, a temperature

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30. Straka, R.M., and Barron, W.R. (1969) Multifrequency solar radio bursts as predictors for proton events, Proc. of Symp. on Ionospheric Forecasting, Grey Rocks, Canada, Conf. Proc. No. 49 paper 10.

31. Bakshi, P., and Barron, W.R. (1975) Spectral Correlations between Solar Flare Radio Bursts and Associated Proton Fluxes, II, AFCRL-TR-75-0579.

32. Hachenberg, O., and Wallis, . . (1961) The Spectrum of Radiofrequency Bursts from the Sun in the Centimeter Wavelengths, Zeit. für Astrophysik, 52, pp. 42-72.

33. Ramaty, R., and Petrosian, V. (1972) Free-Free Absorption of Gyrosynchrotron Radiation in Solar Microwave Bursts, Stanford Univ., Institute of Plasma Research Rpt. No. 465.

of $\sim 10^{6o}K$ and an emission measure of $\sim 4 \times 10^{49}$ cm^{-3} in the emitting region. Obviously, some of the flux densities cited in Table 5 are close to or slightly less than 50 flux units.

The Ramaty and Petrosian investigation did not address proton association for this type radio spectrum. However, Sakurai[26] noted this type spectrum and related it to delayed onset type proton events as we have found. His average radio flux density values were several hundred sfu. We relate the causative difference between the prompt and delayed proton onset to the energy of the solar cosmic rays. Sakurai[26] found intense microwave emission bursts were associated with solar flares related to fast onset proton events. Moreover, the rapidness of flare development was found to be an important factor for the acceleration efficiency of flare associated protons.

It is impossible to determine what conditions arise in the solar flare region to one time produce flat spectra bursts with lower energies, and at another time to produce intense short cm bursts with U-shape spectra and higher energy particles. For example, when a very impressive region is on the sun, both types of burst spectra may be observed, say a day apart. Hence, the signature of flat bursts is not to be found in the macroscopic features of the region.

From a prediction viewpoint, it appears that for the rapid onset catastrophic geophysical events there is a reliable radio signature. When advance warning is not so important as in the case of small proton events with somewhat delayed onset, there is also a radio signature in the burst integrated flux density with a threshold of about 10^{-17} J m^{-2} Hz^{-1}. In the final analysis, it may be that, since delay to onset and duration are related to the proton energy distribution, more effort in the proton spectrum prediction area should be a recommendation from this study.

References

1. Castelli, J.P. (1968) Observation and Forecasting of Solar Proton Events, AFCRL-68-0104.
2. Castelli, J.P. (1969) Short term prediction of solar proton events, Proc. of Symp. on Ionospheric Forecasting, Grey Rocks Canada, Conference Proceedings No. 49.
3. Castelli, J.P., Aarons, J., and Michael, G.A. (1967) Flux density measurements of radio bursts of proton producing and non-proton flares, J. Geophys. Res. 72:5491-5498.
4. O'Brien, W.E. (1970) The Prediction of Solar Proton Events Based on Solar Radio Emissions, AFCRL-70-0425.
5. Bailey, D.K. (1964) Polar cap absorption, Planetary Space Sci. 12:495-541.
6. Castelli, J.P., and Barron, W.R. (1977) A catalog of solar radio bursts of 1966-1976 having spectral characteristics predictive of proton activity, J. Geophys. Res. 82(No. 7):1275-1278.
7. Castelli, J.P., and Aarons, J. (1968) The spectra of microwave solar bursts, Astron. J. Supplement 72(Pt II)(5):S57-S58.
8. Castelli, J.P., and Guidice, D.A. (1970) On the distribution and interpretation of microwave solar burst data, Proc. 1970 G-AP International Symposium, Columbus, Ohio, p. 83-93.
9. Castelli, J.P., and Guidice, D.A. (1972) On The Classification, Distribution and Interpretation of Solar Microwave Burst Spectra and Related Topics, AFCRL-72-0049.
10. Guidice, D.A., and Castelli, J.P. (1972) Spectral characteristics of microwave bursts, Proc. of NASA Symp. on High Energy Phenomena on the Sun, Greenbelt, Md, NASA SP-342, pp. 87-103.
11. Guidice, D.A., and Castelli, J.P. (1975) Statistical characteristics of the peak flux density spectra of solar microwave bursts Solar Physics 44: 155-172.

12. National Oceanic and Atmospheric Administration (1966-1976) Solar Geophysical Data Bulletins.

13. Cormier, R.J. (1970) Polar Riometer Observations, AFCRL-70-0690.

14. Cormier, R.J. (1973) Thule Riometer Observations of Polar Cap Absorption Events (1962-1972), AFCRL-TR-73-0060.

15. Masley, A.J. (1971) The McDonnell Douglas Geophysical Observatory Progress Report X, MDC-G2736.

16. Masley, A.J., and Satterblom, P.R. (1969) A discussion of solar cosmic ray activity near sunspot maximum, Proc. 11th Int. Conf. on Cosmic Rays, Budapest, 1969, p. 513-519.

17. Masley, A.J., McDonough, J.W., and Satterblom, P.R. (1970) Solar Cosmic Ray Observations During 1969, Antarctic Journal of the U.S., 5(No. 5):127.

18. Masley, A.J. (1974) The McDonnell Douglas Geophysical Observatory Program Progress Report XII, MDC G5190.

19. Castelli, J.P., and Aarons, J. (1970) Short Term Prediction of Solar Proton Events, McGraw Hill Yearbook of Science and Technology, D.N. Lapedes, Ed., pp. 353-357.

20. Dodson, H.W., Hedeman, E.R., Kreplin, R.W., Martres, M.J., Obdriko, V.N., Shea, M.A., Smart, D.F. and Tanaka, H. (1975) Catalog of Solar Particle Events 1955-1969, Vol. 49 of Astrophysics and Space Science Library, Ed. by Z. Svestka and P. Simon, D. Reidel Pub. Co., Dordrecht, Holland.

21. Carrigan, A.L., Ed. (1970) AFCRL Geophysics and Space Data Bulletin, 1970 (4th Quarter-1974, Appendix A).

22. Shea, M.A., and Smart, D.F. (1978) Significant Proton Events, 1955-1969, AFGL-TR-78-0028.

23. Van Hollebeke, M.A.I., Sung, L.S., and McDonald, F.B. (1975) The Variation of Solar Proton Energy Spectra and Size Distribution with Heliolongitude, Solar Physics, 41, pp. 189-223.

24. International Astronomical Union (1966-1971) Quarterly Bulletin of Solar Activity, Waldmeier Ed., published by Eidgenossische Sternwarte, Zurich.

25. Pomerantz, M.A., and Duggal, S.P. (1974) The sun and cosmic rays, Reviews of Geophysics and Space Physics, 12(No. 3):343-361.

26. Sakurai, K. (1974) Energetic Particles from the Sun, Astrophysics and Space Science, D. Reidel Pub. Co., 28, pp. 375-519.

27. Smart, D.F., Shea, M.A., Dodson, H.W., and Hedeman, E.R. (1976) Distribution of Proton Producing Flares Around the Sun, Space Research XVI, Akademie-Verlag, Berlin, pp. 797-802.

28. Reinhard, R., and Wibberenz, G. (1974) Propagation of Flare Protons in the Solar Atmosphere, Solar Physics, 36, pp. 473-494.

29. Sung, L.S. Ma. (1977) A Study of the Propagation and Intrinsic Characteristics of Flare Associated Particle Events, NASA GSFC rpt No. X-660-77-1113.

30. Straka, R.M., and Barron, W.R. (1969) Multifrequency solar radio bursts as predictors for proton events, Proc. of Symp. on Ionospheric Forecasting, Grey Rocks, Canada, Conf. Proc. No. 49 paper 10.

31. Bakshi, P., and Barron, W.R. (1975) Spectral Correlations between Solar Flare Radio Bursts and Associated Proton Fluxes, II, AFCRL-TR-75-0579.

32. Hachenberg, O., and Wallis, G. (1961) The Spectrum of Radiofrequency Bursts from the Sun in the Centimeter Wavelengths, Zeit. für Astrophysik, 52, pp. 42-72.

33. Ramaty, R., and Petrosian, V. (1972) Free-Free Absorption of Gyrosynchrotron Radiation in Solar Microwave Bursts, Stanford Univ., Institute of Plasma Research Rpt. No. 465.